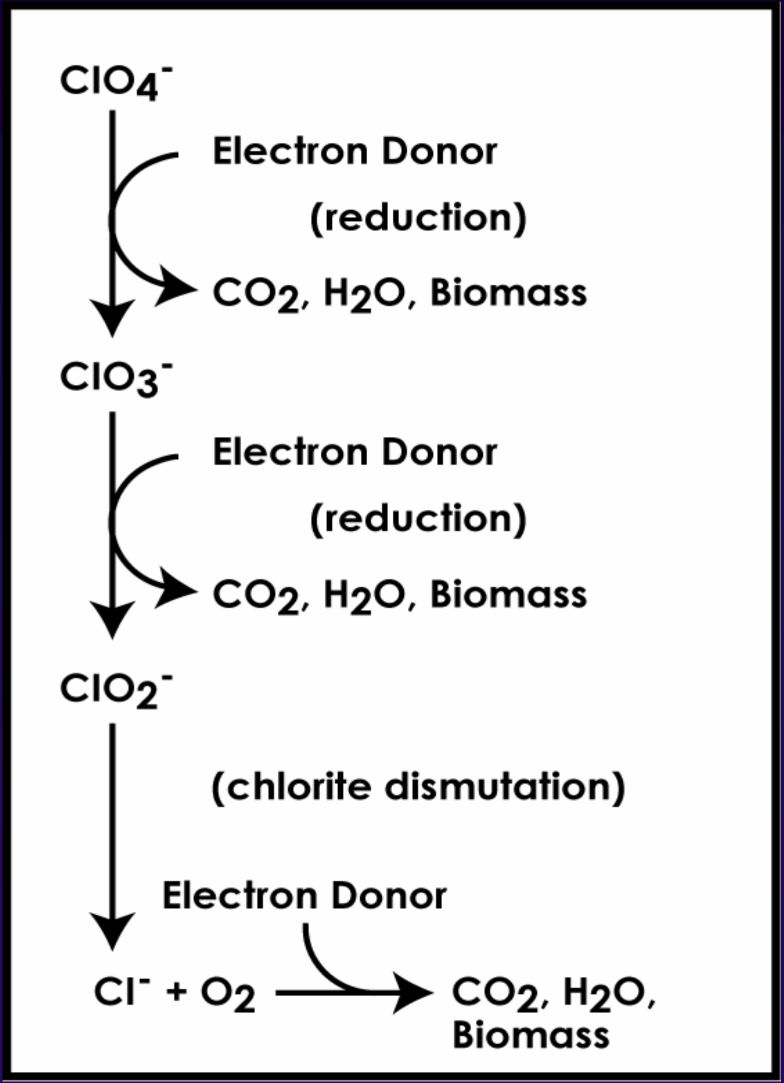
Cost-Effective Bioremediation of Perchlorate in Soil & Groundwater

Evan Cox - GeoSyntec Consultants
Elizabeth Edwards - University of Toronto
Scott Neville & Michael Girard - Aerojet

Outline

- Perchlorate Biodegradation
- Groundwater In Situ Bioremediation
    - SERDP Study to Assess DoD Applicability
    - Aerojet Field Demonstration
- Soil Bioremediation Demonstrations
- Phytoremediation Demonstrations

Perchlorate Biodegradation Mechanism



- Bacteria present in soil, water & wastes can use perchlorate as an electron acceptor
- A wide variety of carbon substrates can serve as electron donors
  - Sugars (molasses)
  - Alcohols (methanol, ethanol)
  - Volatile Acids (acetate, lactate)
  - Wastes (food processing, manure)
- Reaction occurs under anaerobic-reducing conditions

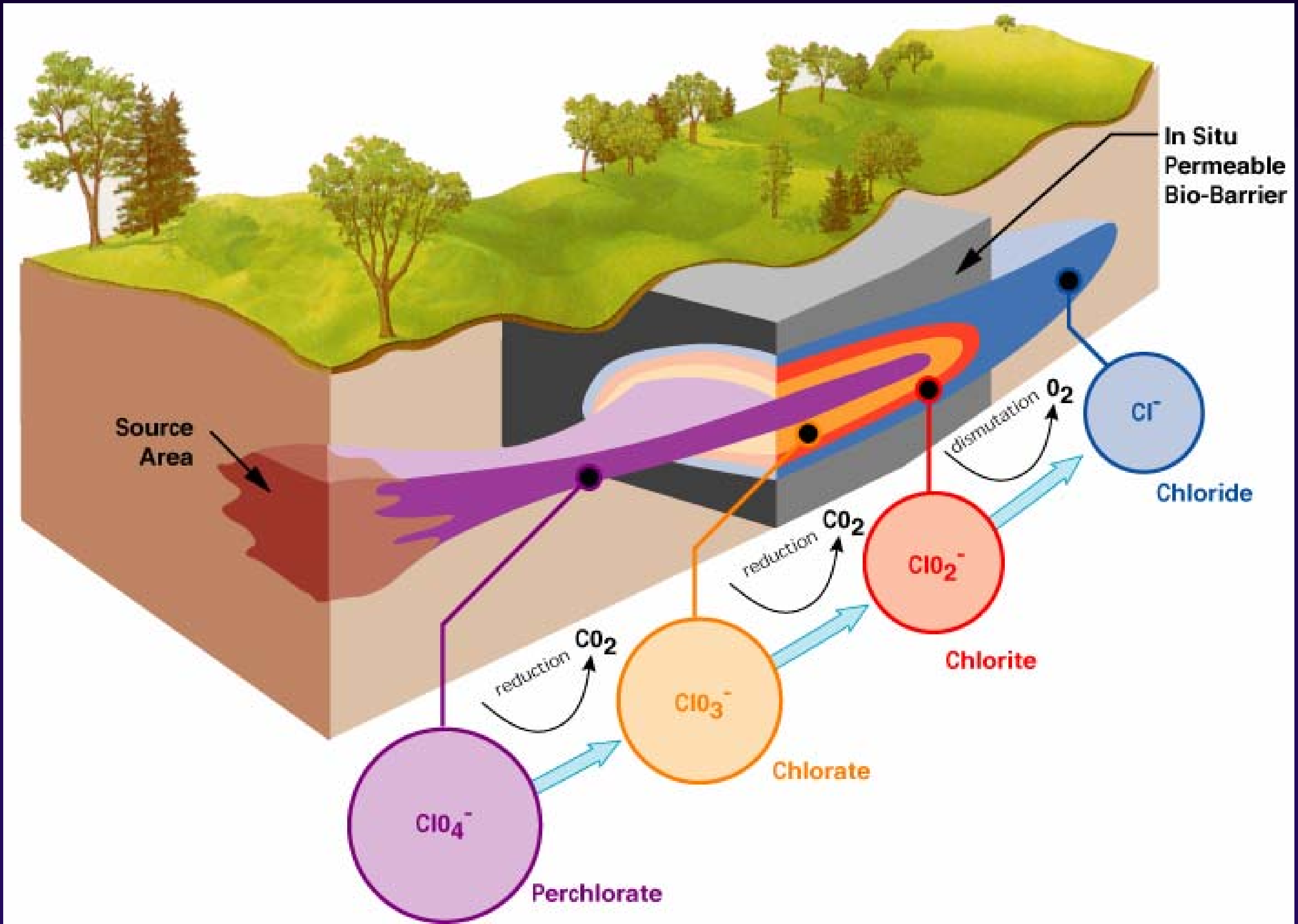
Groundwater
In Situ Bioremediation

In Situ Bioremediation Goals

1. Destruction of source areas to reduce remedial duration and cost
2. Passive/semi-passive in situ bio-barriers to prevent $Cl0_4$ migration in GW or discharge to SW

In situ bio can be coupled with other (ex situ) technologies

In Situ Bioremediation Concept



Strategic Environmental Research & Development Program (SERDP)

SERDP
Strategic Environmental and Development Program

Improving Mission Readiness
Environmental Research

In Situ Bioremediation of Perchlorate in Groundwater

GeoSyntec, University of Toronto & Aerojet

SERDP Research Goals

- Evaluate the ubiquity of perchlorate biodegraders and the applicability of in situ bioremediation
- Assess geochemical tolerance ranges
  - concentration, pH, salinity
  - competing electron acceptors (nitrate, sulfate)
- Treatment of mixed plumes (TCE, BTEX, NDMA)
- Field demonstration

SERDP Test Sites

1. Edwards AFB, California
2. US Navy, West Virginia
3. US Navy, California
4. Rocket Manufacturer, California
5. Aerojet Superfund Site, California

6. Industrial Site, Nevada

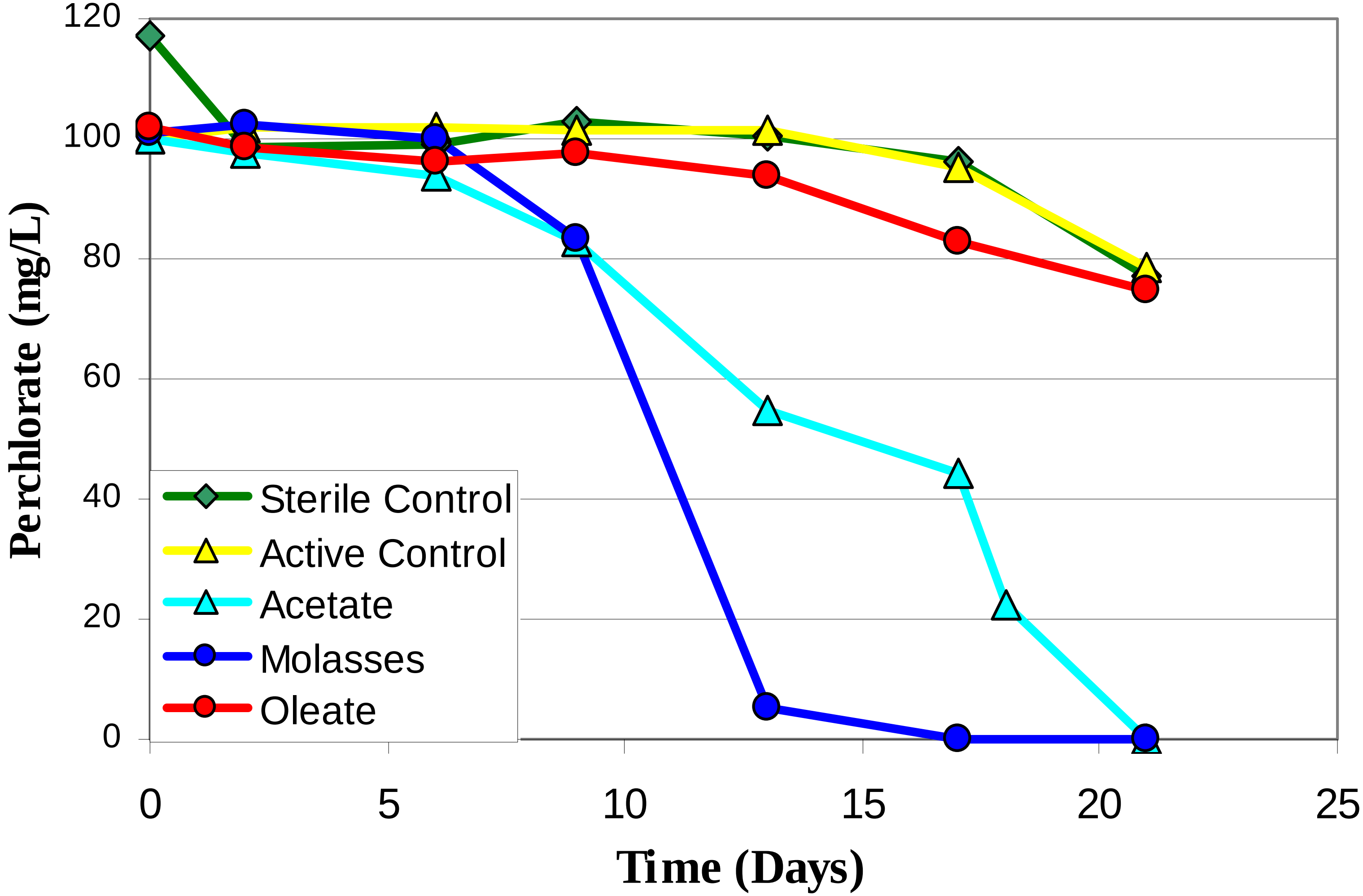
SERDP Task 1 - Site Screening

- Laboratory microcosm testing using soil and groundwater from geochemically different sites
- Assess level of intrinsic degradation
- Evaluate potential to enhance biodegradation through addition of various electron donors (acetate, molasses, oils)
- Identify sites for further lab/field pilot testing

Site 1. Edwards Air Force Base, CA

- Rocket manufacturing site
- Alluvial deposits to > 250 feet bgs
- Watertable at ~125 ft bgs
- ClO_4 up to 160 mg/L
- Nitrate = 1 mg/L, Sulfate = 180 mg/L
- Oxygen = 2 mg/L, Redox = +200 mV
- Chloride = 360 mg/L, pH = 6.2

Site 1. Edwards Air Force Base, CA

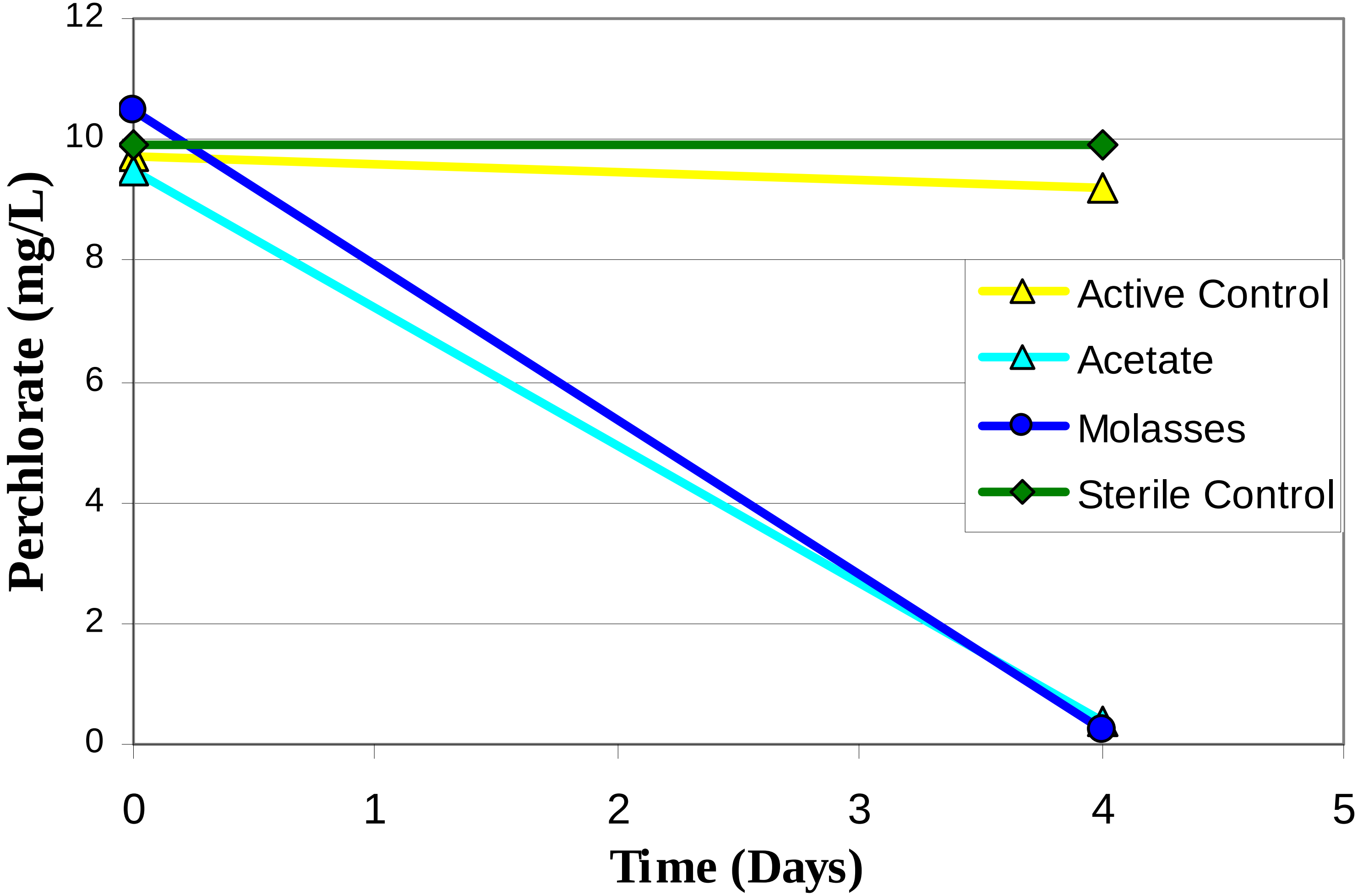


Data are average of triplicate microcosms; MDL = 0.05 mg/L

Site 2. U.S. Navy, West Virginia

- Ballistics testing facility
- Sandy silt alluvium (20 ft) over fractured bedrock
- Watertable at ~15 ft bgs
- ClO_4 in groundwater ~ 10 mg/L
- Nitrate = 4 mg/L, Sulfate = 55 mg/L
- Redox (ORP) = 285 mV
- Chloride = 25 mg/L, pH = 6.7

Site 2. U.S. Navy, West Virginia



Data are average of triplicate microcosms; MDL = 0.05 mg/L

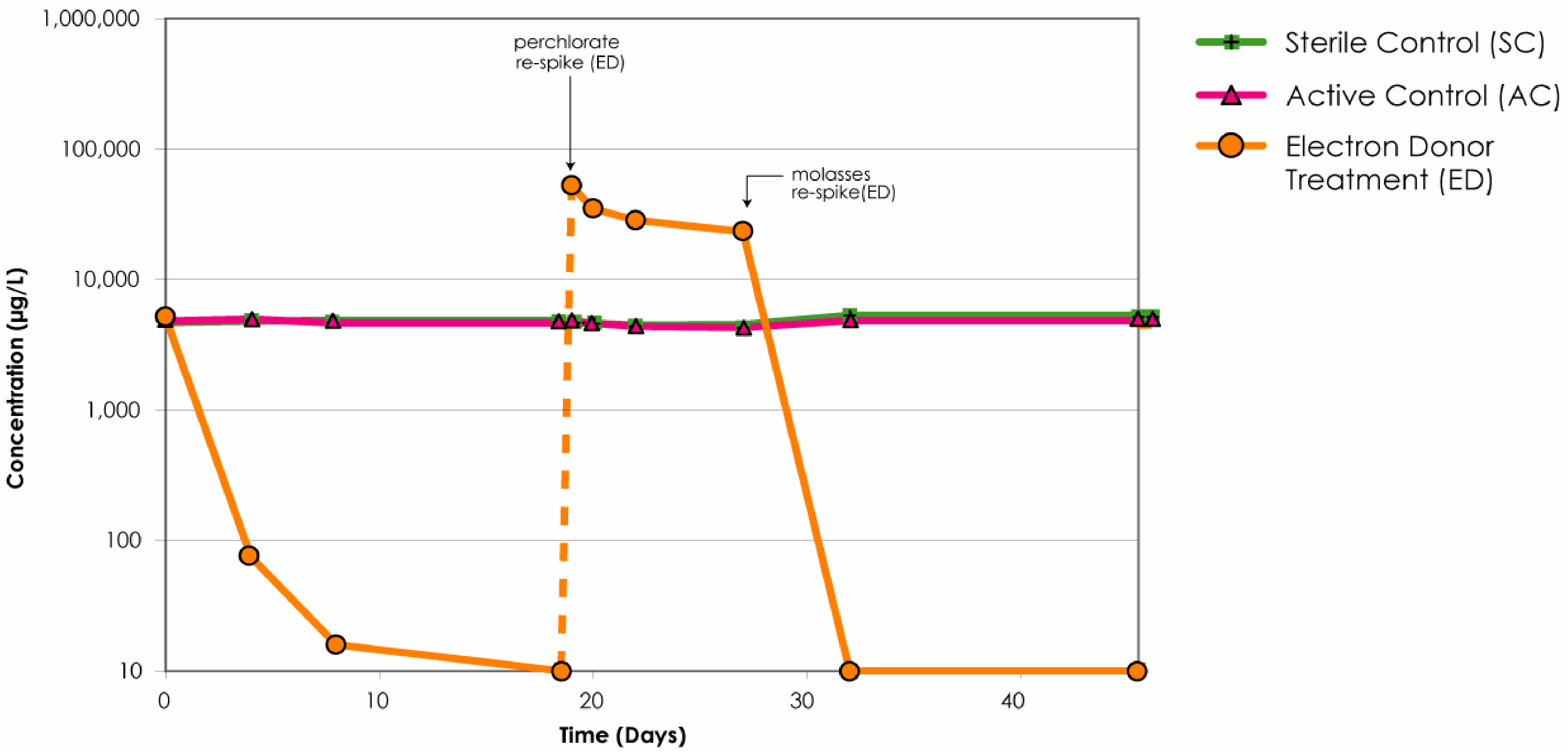
Site 3. U.S. Navy, California

- Exploded ordinance disposal facility
- Medium to coarse beach sand
- Watertable at ~20 ft bgs
- ClO_4 up to 190 mg/kg in surface drainages
- ClO_4 in groundwater up to 200 µg/L
- Nitrate = 4 mg/L, Sulfate = 82 mg/L
- Redox (ORP) = 285 mV
- Chloride = 865 mg/L

Site 4. Rocket Site, California

- Active ClO_4 grinder station
- Silts to fine sands
- Watertable at ~15 ft bgs
- ClO_4 up to 1,200 mg/L in groundwater
- Nitrate = 2 mg/L, Sulfate = 75 mg/L
- Redox (ORP) = -10 mV
- VOCs (TCE, TCA) also present

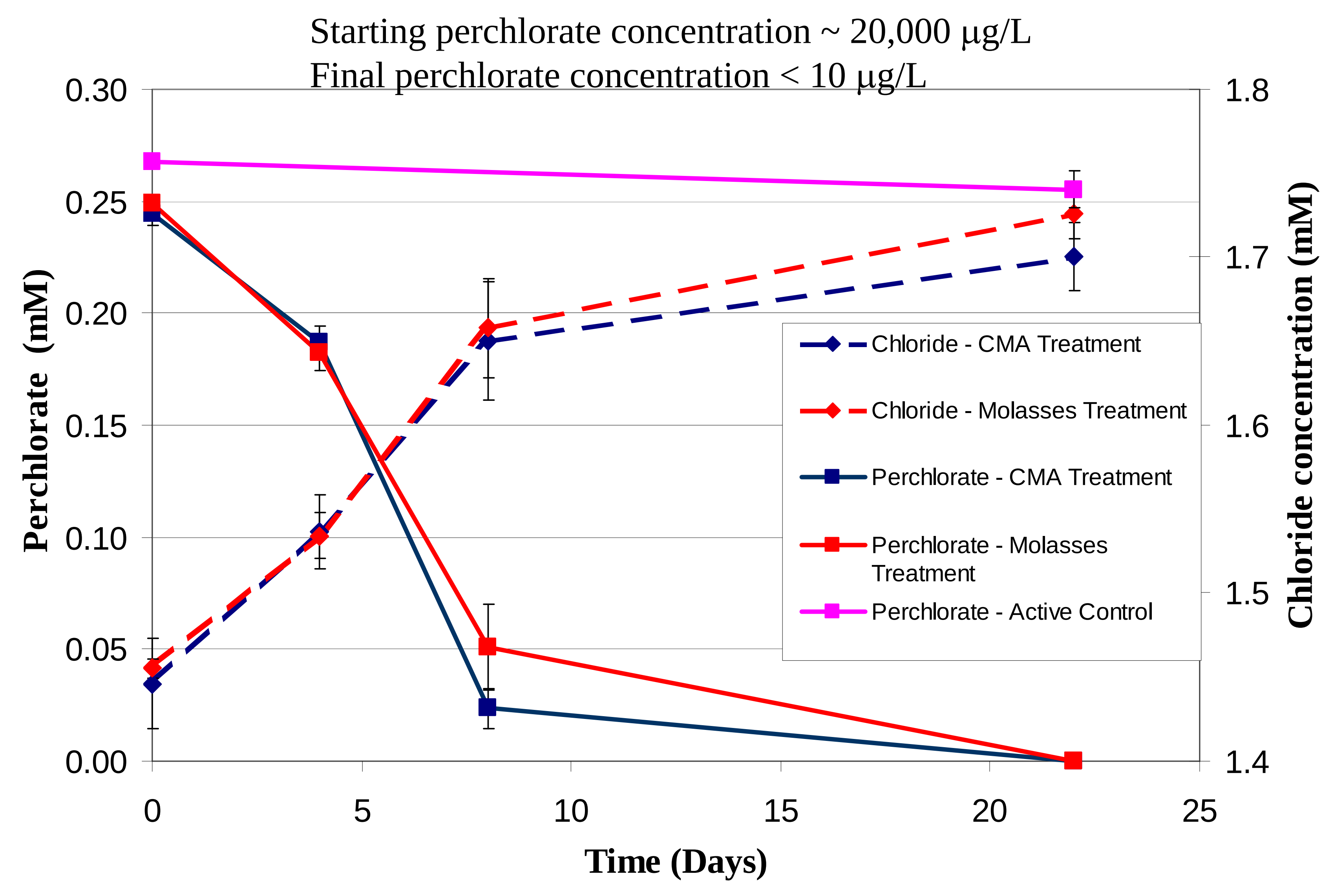
Site 4. Rocket Site, California



Site 5. Aerojet Superfund Site

- Alluvial aquifer, interbedded silts, sands and gravel
- Aquifer depth 100 ft bgs, watertable 20 ft bgs
- ClO_4 = 15 mg/L
- Nitrate = 5 mg/L, Sulfate = 10 mg/L
- Oxygen = 4 mg/L, Redox = +200 mV
- TCE = 3 mg/L
- pH = 6.8

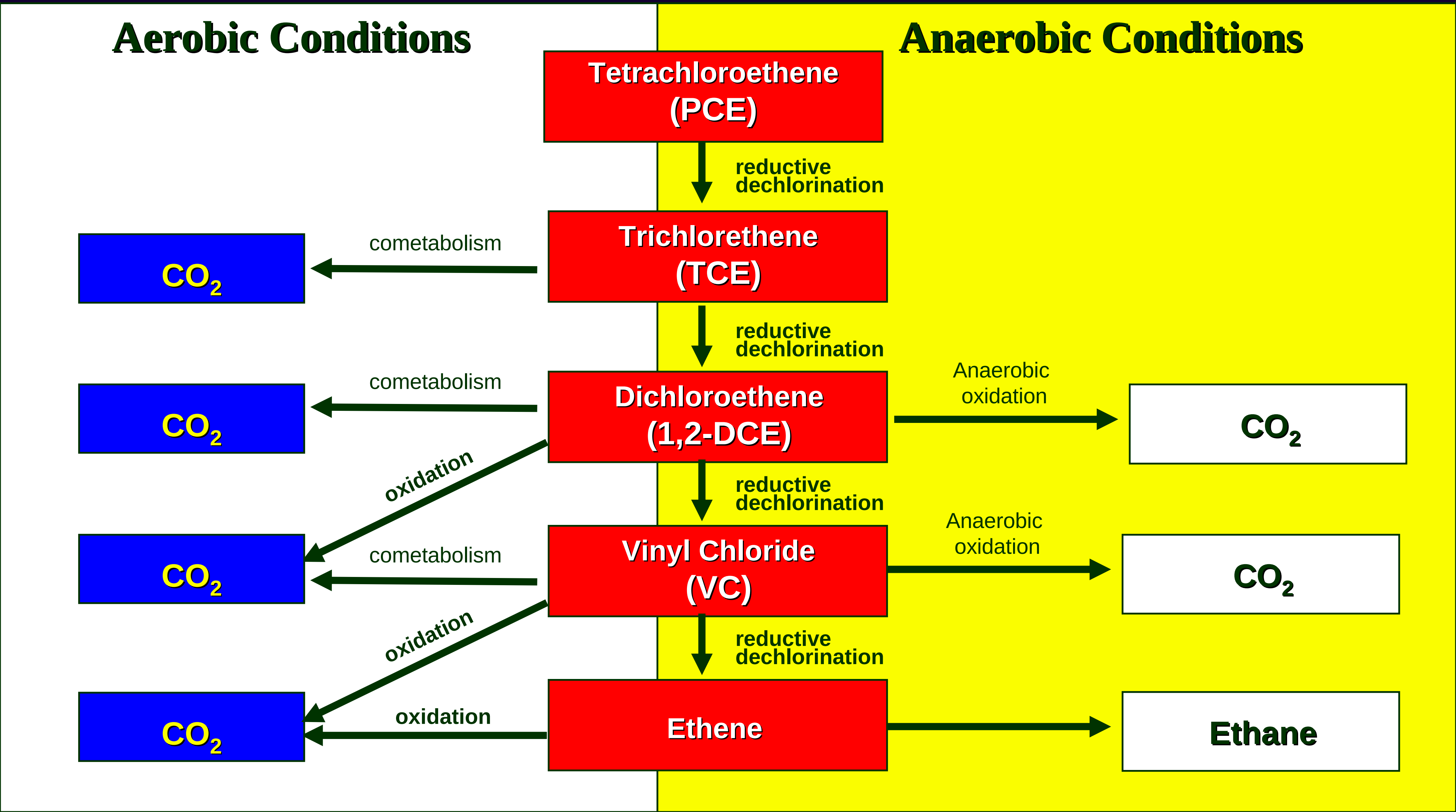
Site 5. Aerojet Superfund Site



Site 5. Joint $Cl0_4$ & TCE Reduction

- Perchlorate plumes are commonly co-mingled with chlorinated solvents (e.g., TCE)
- Both ClO_4 and TCE undergo anaerobic reduction… BUT, microorganisms, mechanisms and redox requirements differ
- Determine whether ClO_4 and TCE can be jointly biodegraded, or whether activities are mutually exclusive
- Demonstrate successful joint bioremediation at field scale

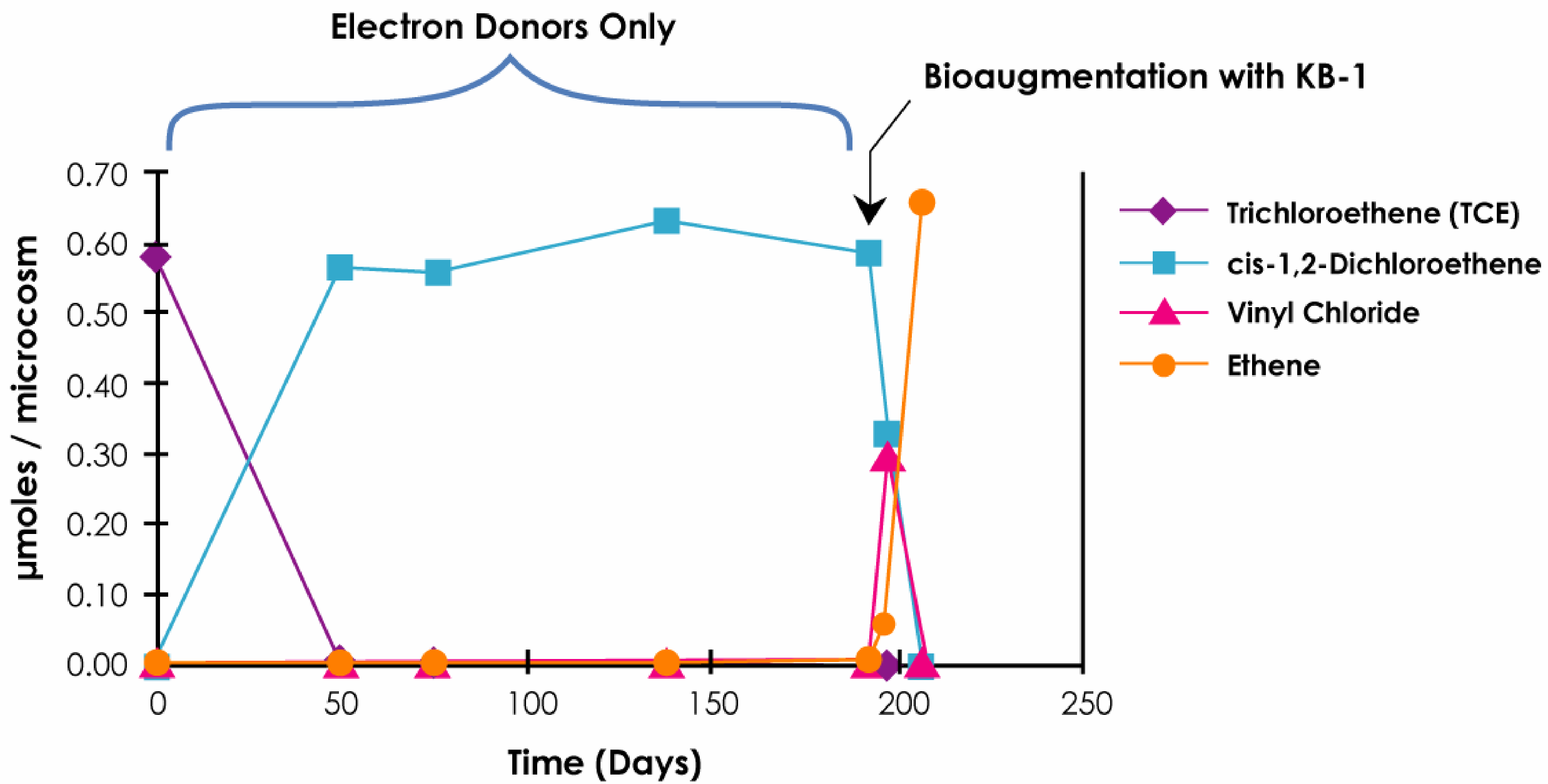
PCE & TCE Degradation Pathways



TCE Dechlorination

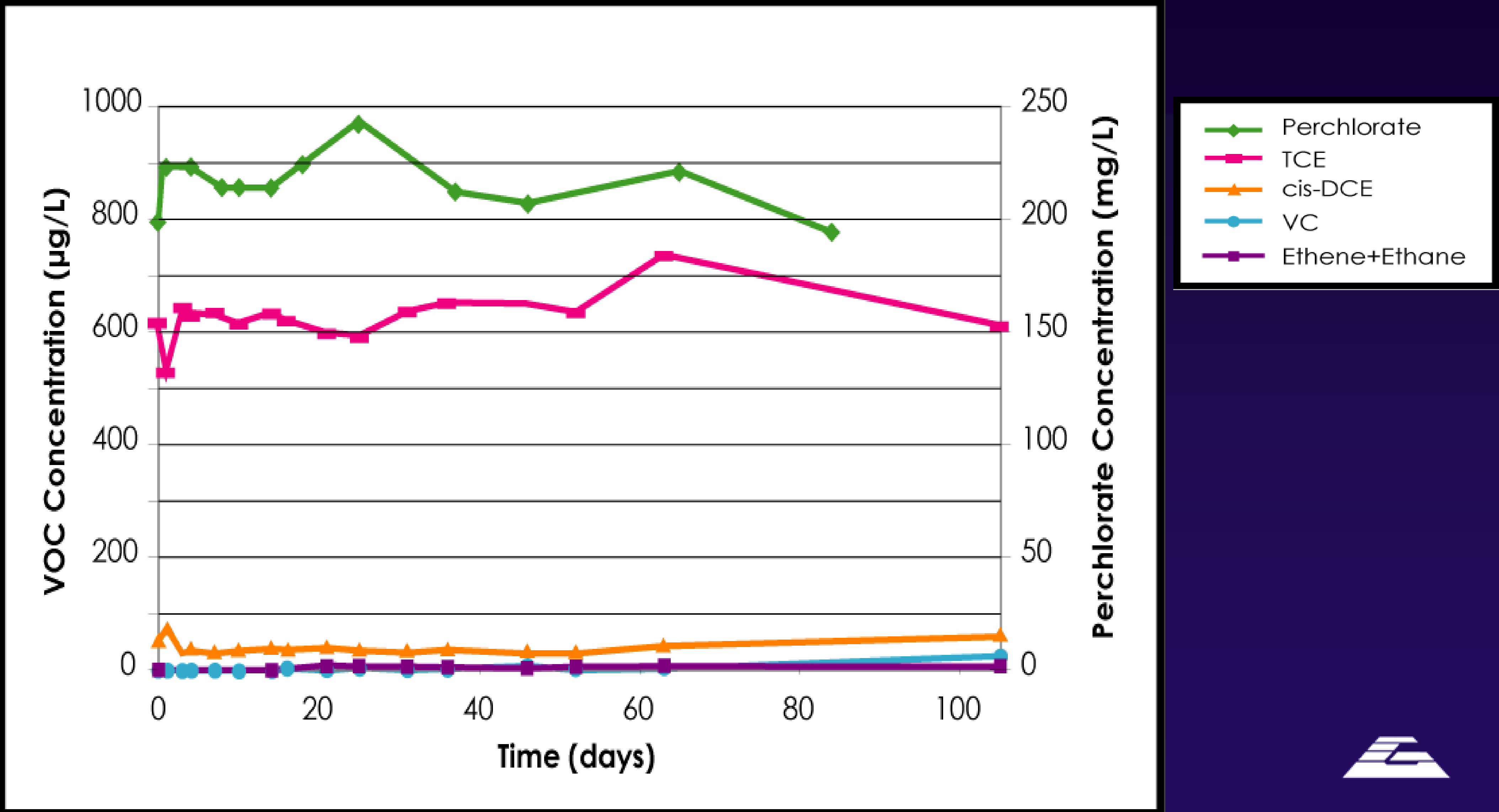
- Specific halo-respiring bacteria mediate TCE dechlorination to ethene
- Halo-respirers are not ubiquitous
- TCE dechlorination often stalls at cis-1,2-DCE
- Cis-1,2-DCE dechlorination to VC is critical step
- Bioaugmentation with KB-1 can promote complete dechlorination to ethene

Bioaugmentation with KB-1, Aerojet Superfund Site

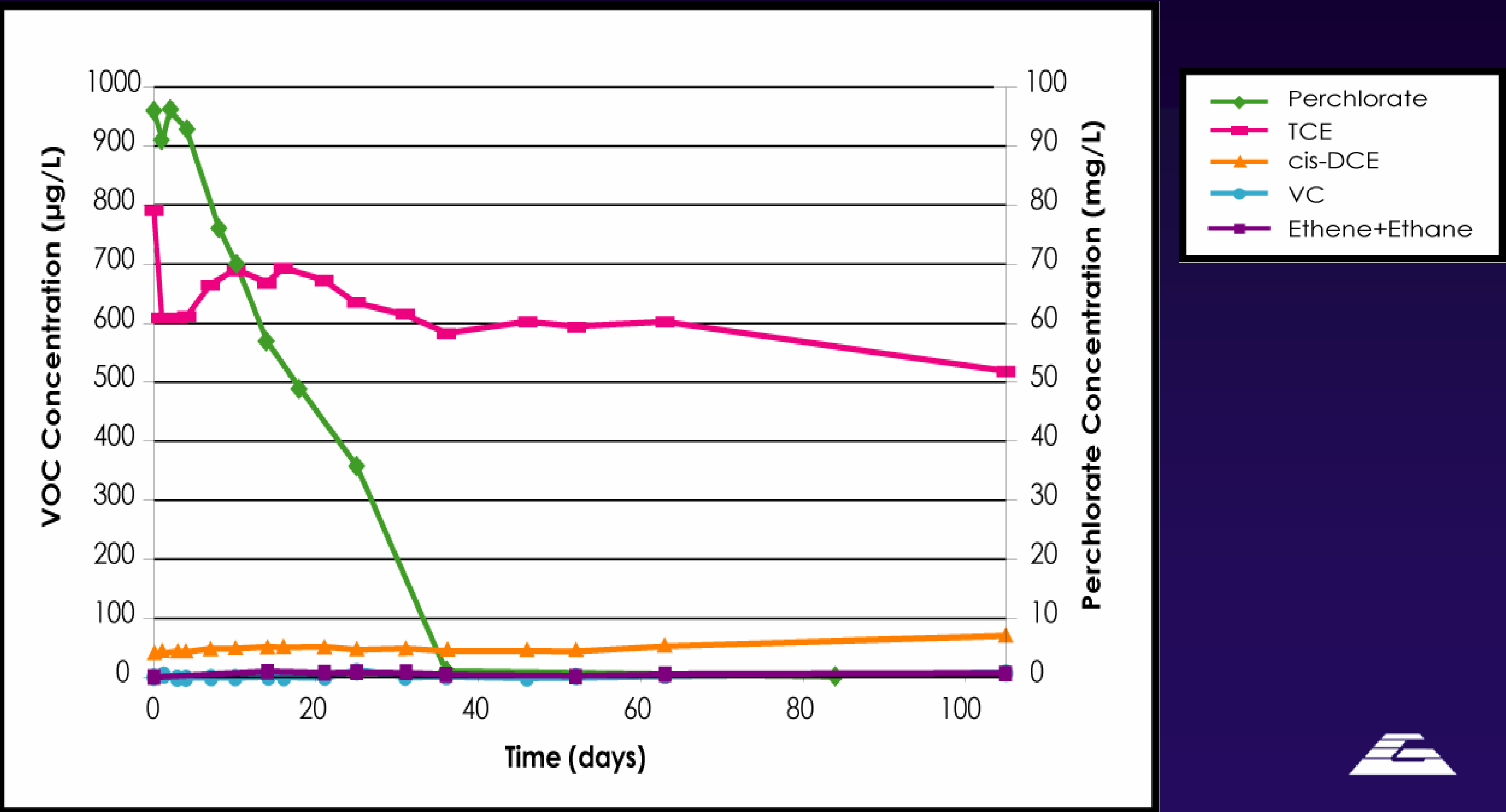


TCE starting concentration = 1,300 µg/L

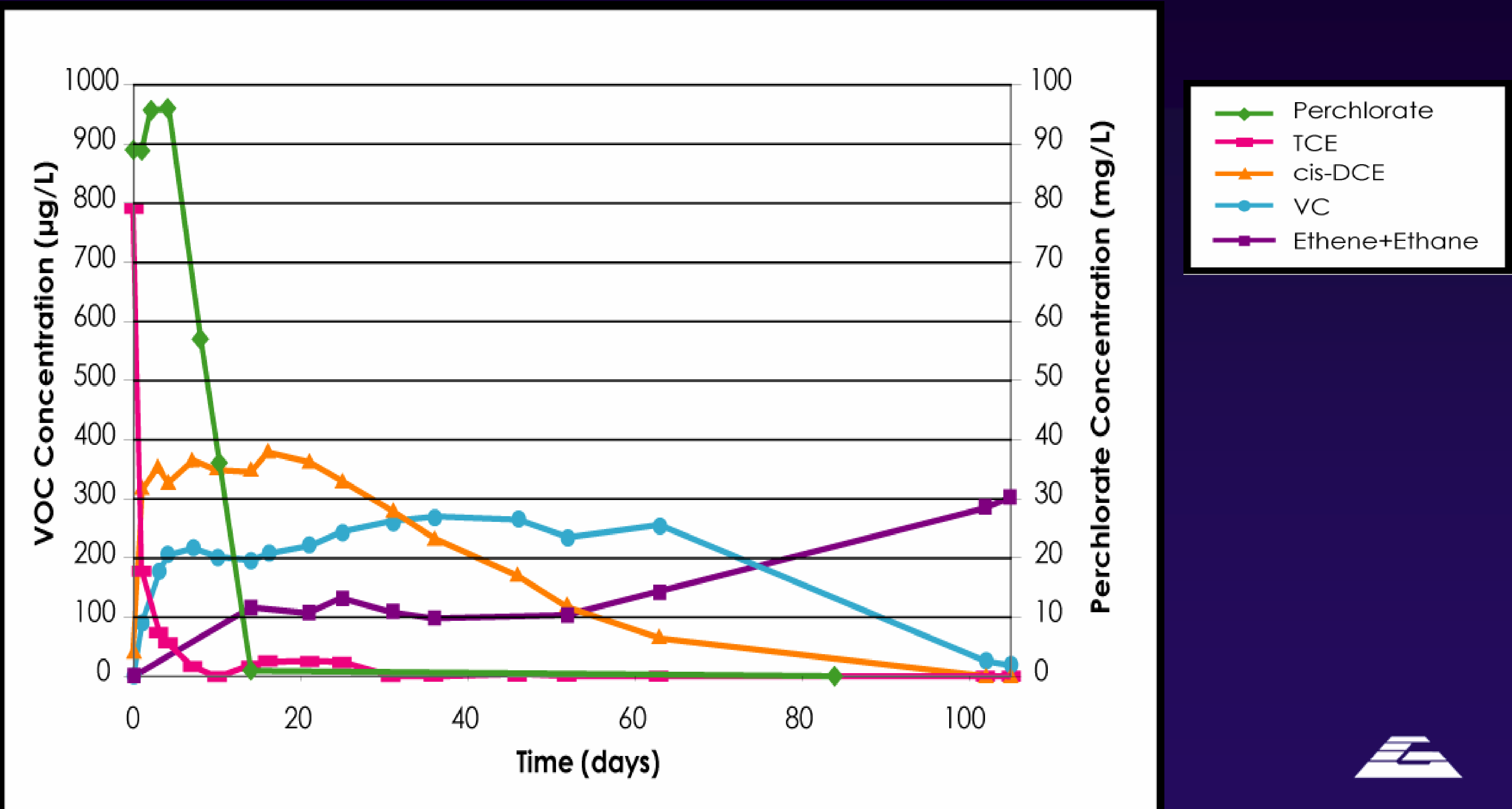
Sterile Control



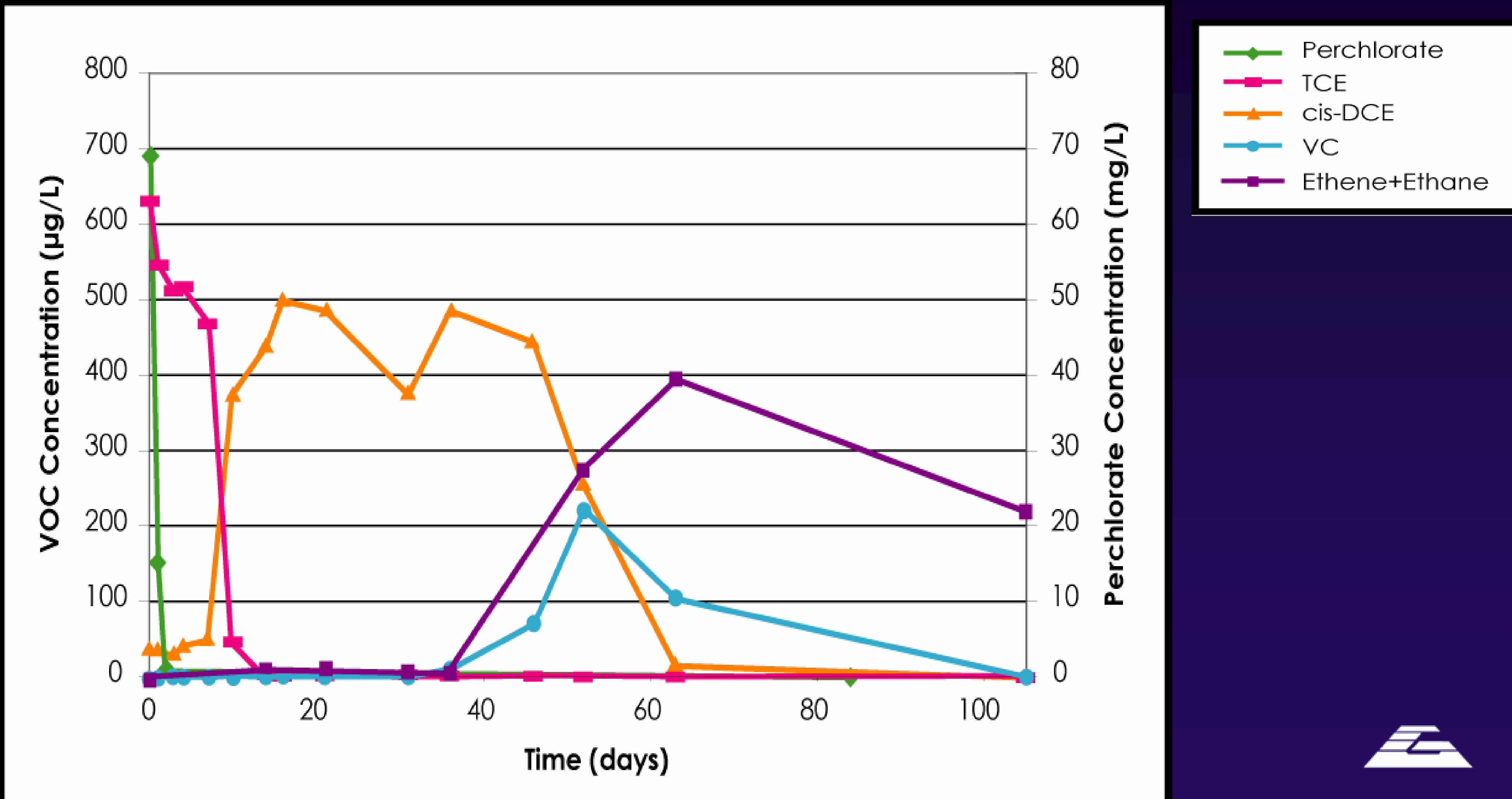
Molasses Treatment



Molasses + TCE Degrader (KB-1)

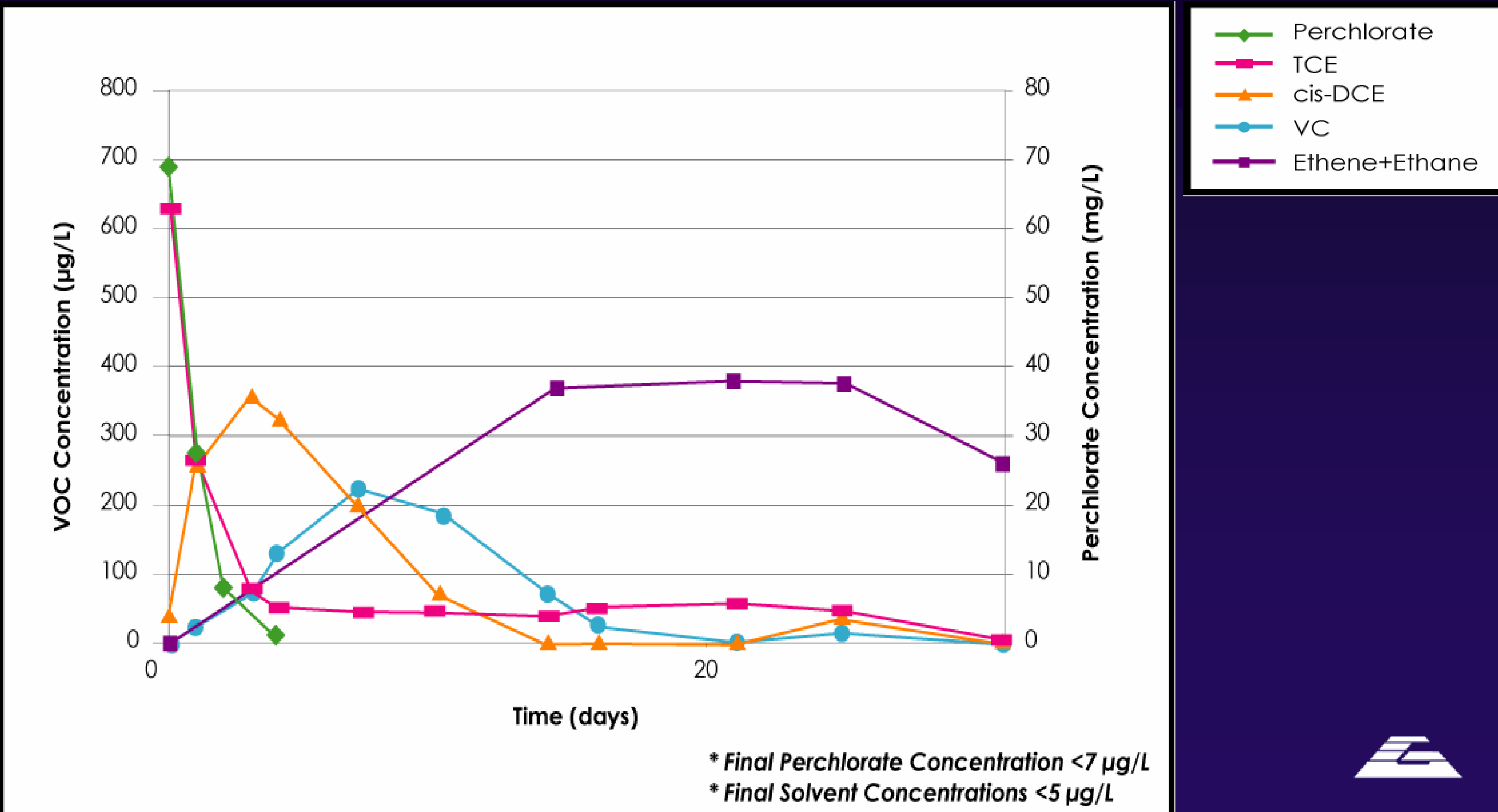


Food Waste



VOC Concentration (µg/L)
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
Time (days)
Perchlorate Concentration (mg/L)
80
70
60
50
40
30
20
10
0
Perchlorate
TCE
cis-DCE
VC
Ethene+Ethane

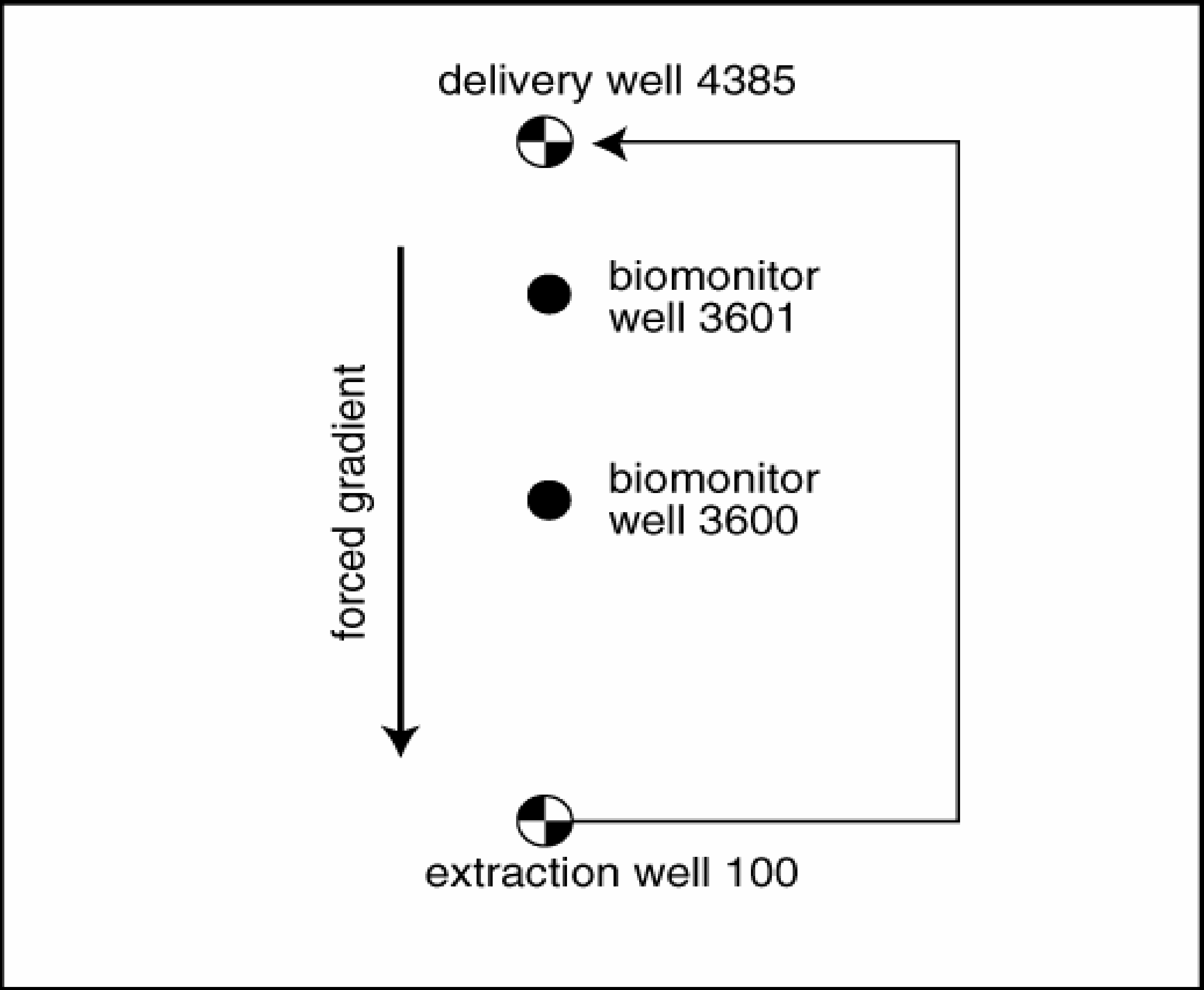
Food Waste + TCE Degrader (KB-1)



Site 5. Aerojet Field Demonstration

- In situ anaerobic bioremediation of ClO_4 & TCE
- Initiated June 2000
- Target aquifer 100 ft bgs
- ClO_4 = 15 mg/L; TCE = 3 mg/L
- Goal: Migration Control for ClO_4 & TCE plume that is 800 feet wide

Plan View of Field Demo Layout

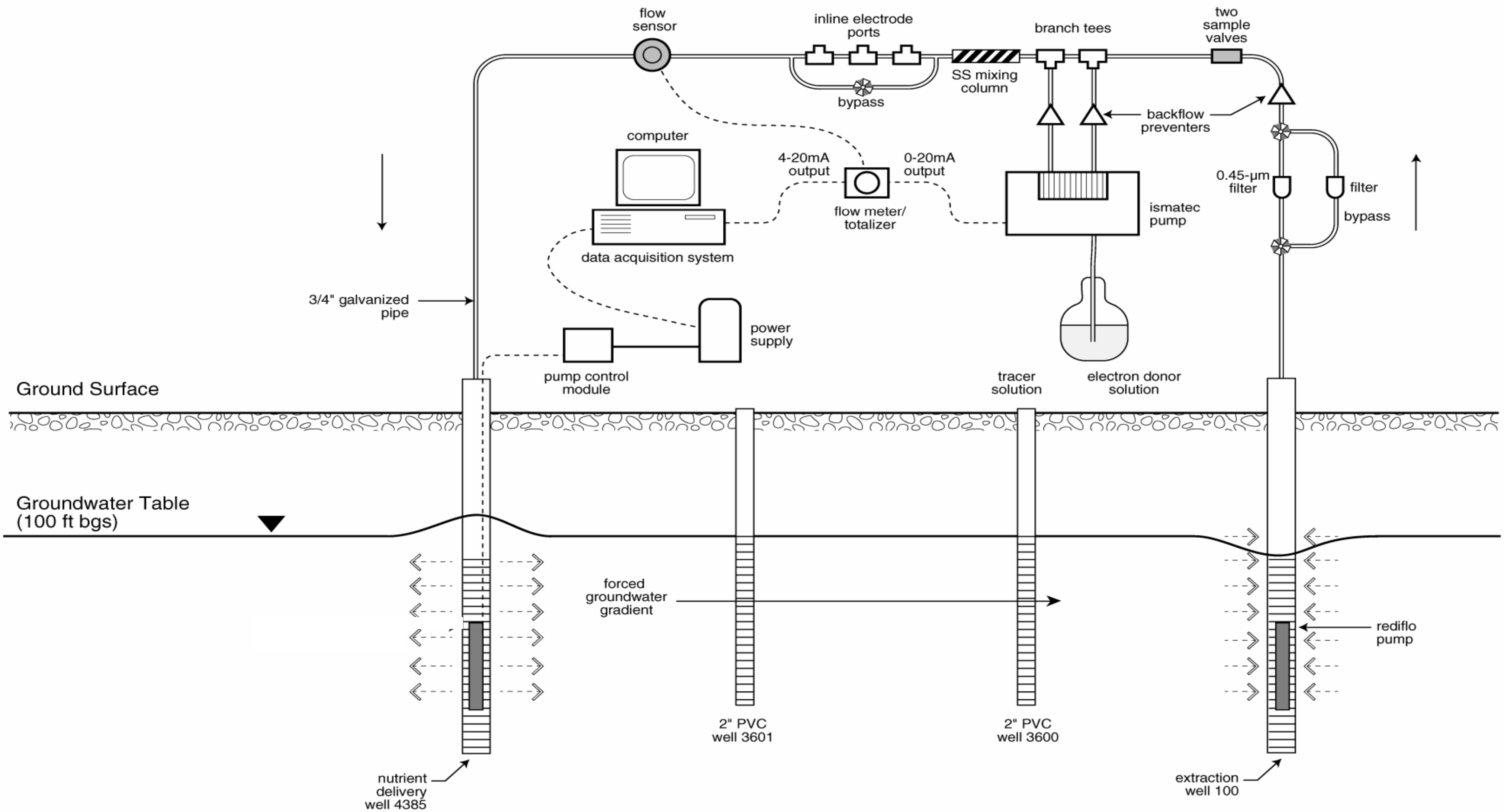


Closed loop (65 feet) re-circulation 5-10 gpm

Residence time = 21 days

Bromide mass retention >90% per pore volume

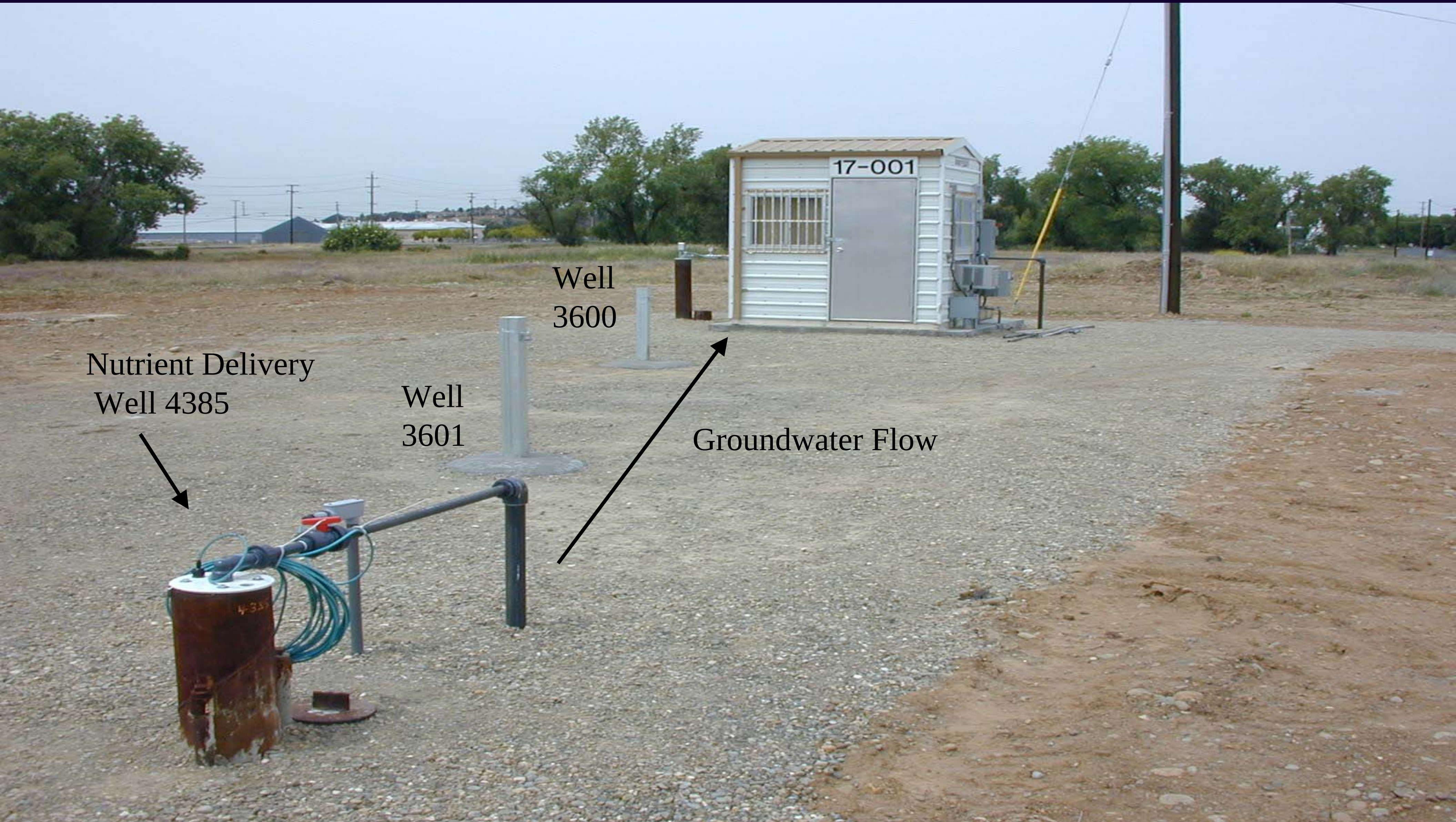
Schematic of Pilot Test System



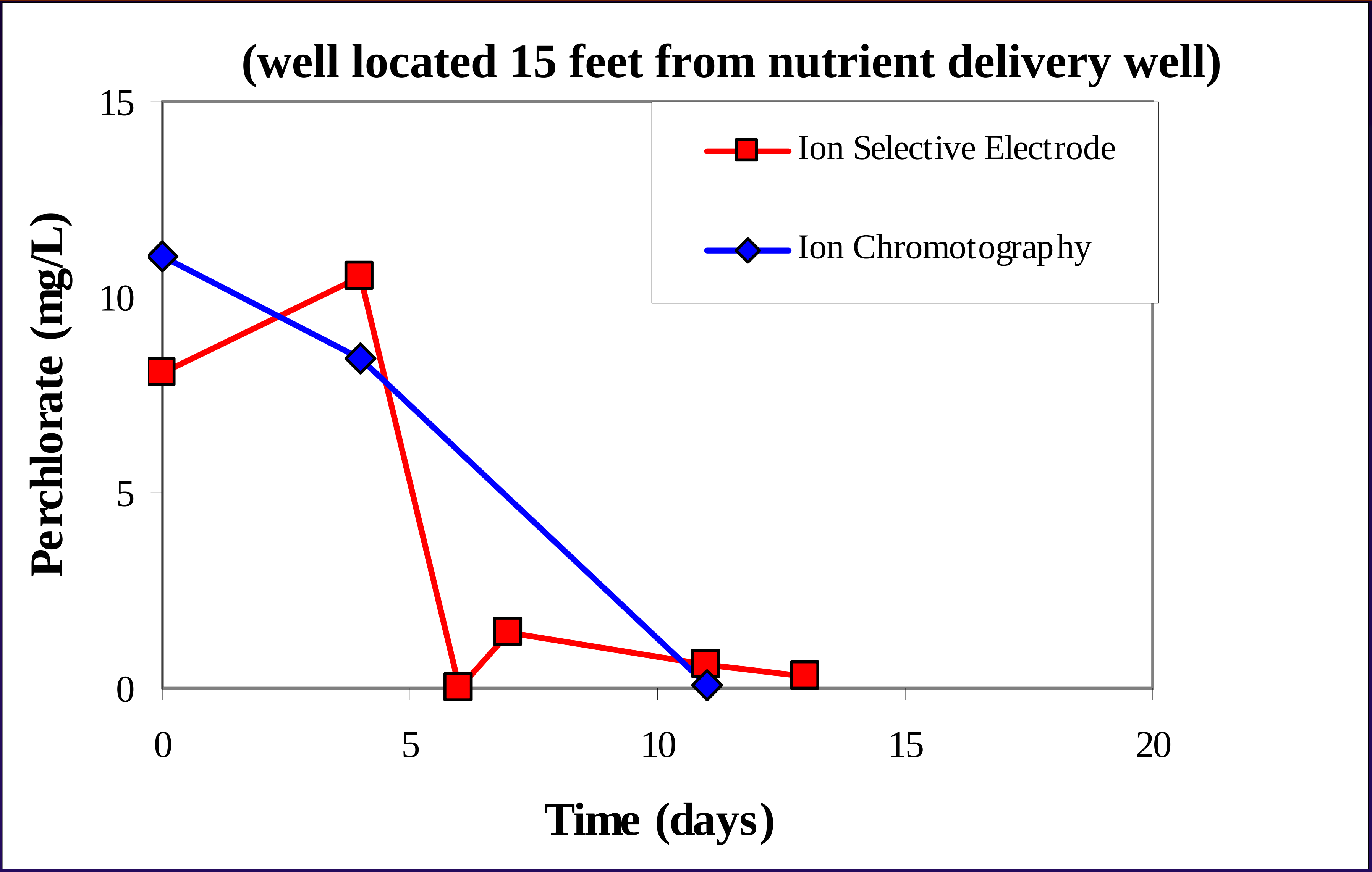
Flow Rate = 5 gpm

Cross Section Schematic
Area 20 Groundwater Pilot

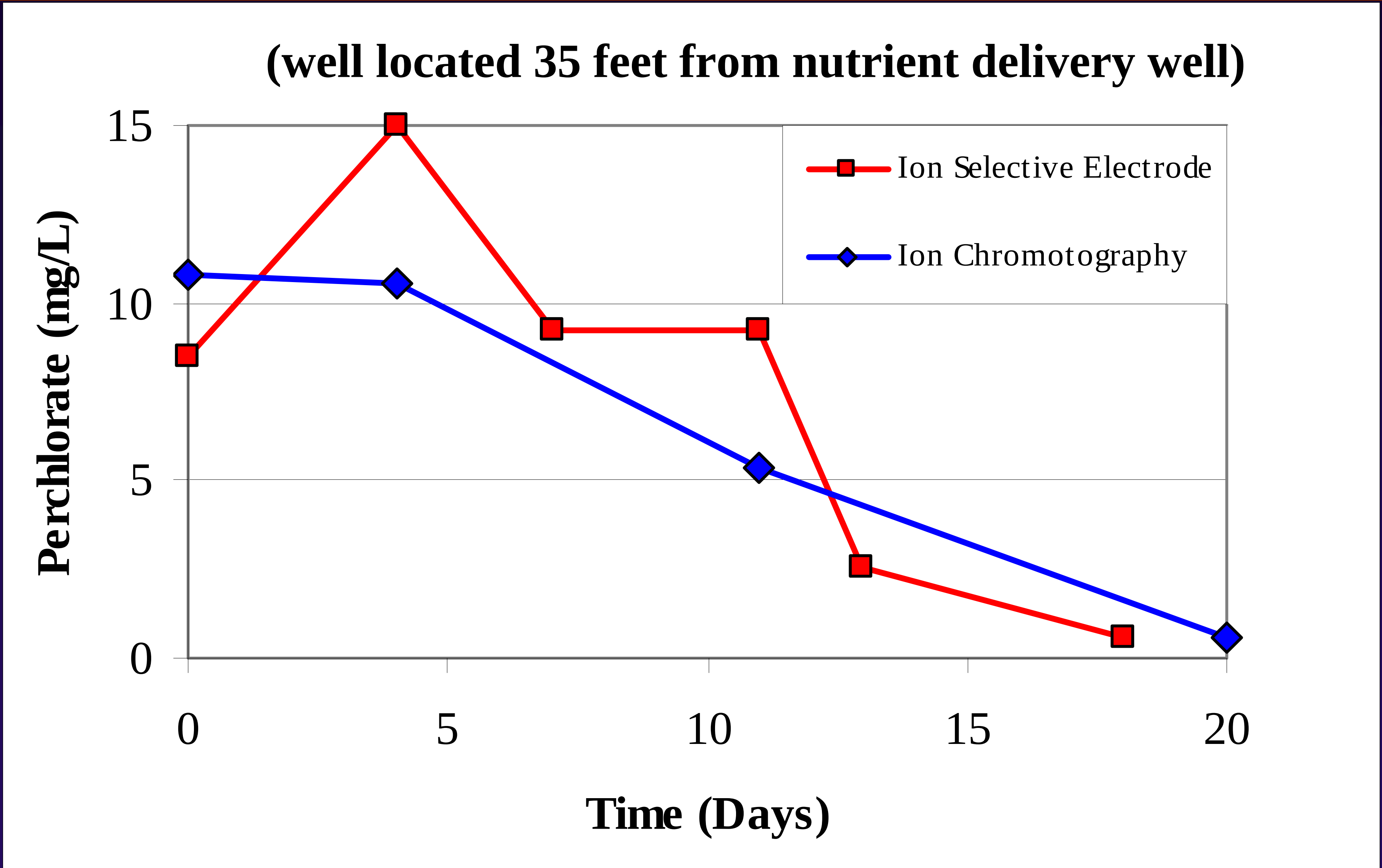
Field Demo Instrumentation



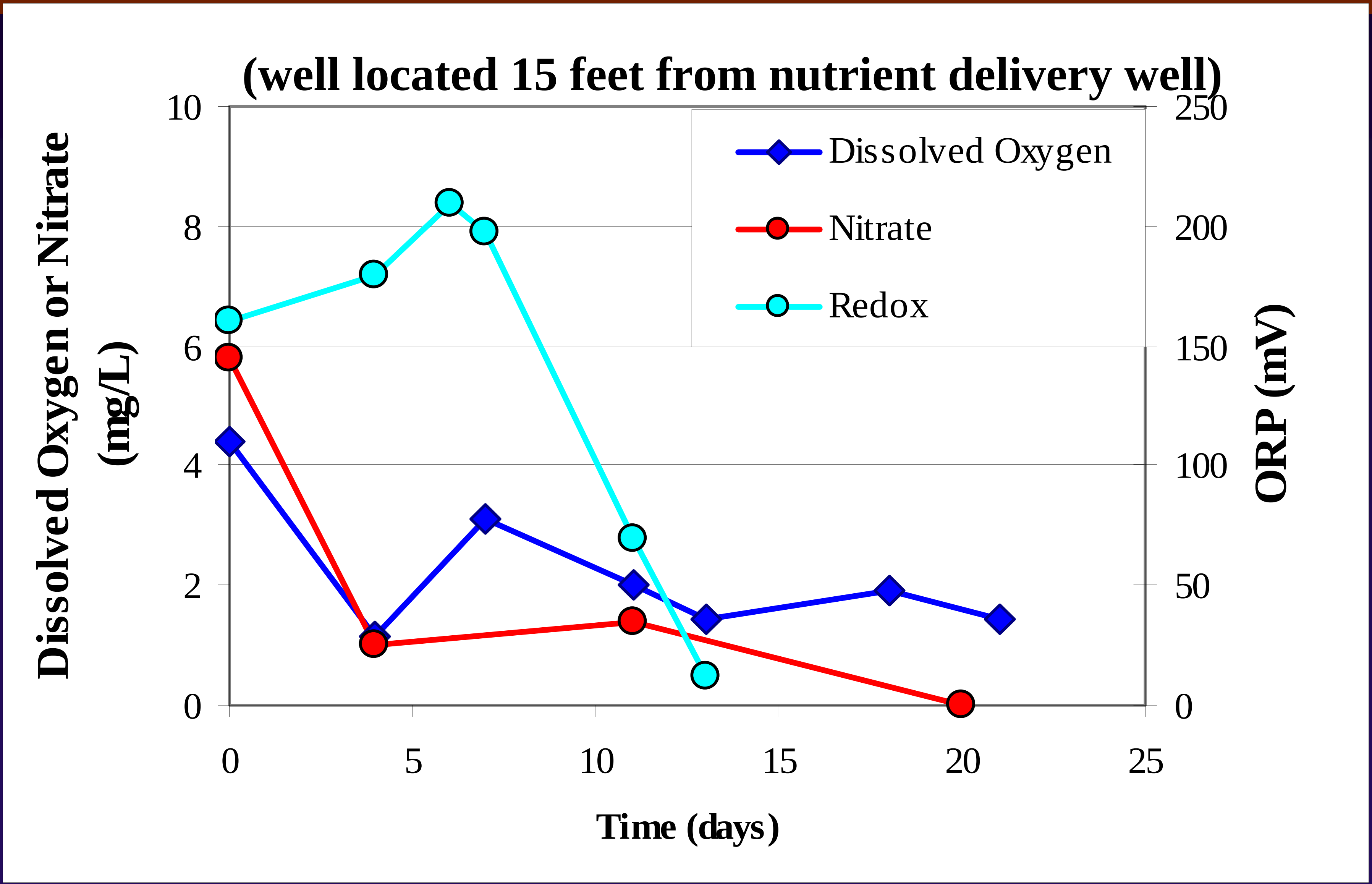
Perchlorate Biodegradation at Well 3601



Perchlorate Biodegradation at Well 3600



Groundwater Geochemistry at Well 3601



Soil Bioremediation

Soil Bioremediation Goals

1. Meet residential/industrial PRGs (37 & 940 mg/Kg)
2. Reduce perchlorate infiltration to groundwater and/or overland flow to surface waters (> PAL of 18 ppb)
   - Ex situ treatment for accessible impacted soils
   - In situ treatment (via mixing, flushing, gas delivery) for deeper unsaturated soils (long-term sources for GW impact)

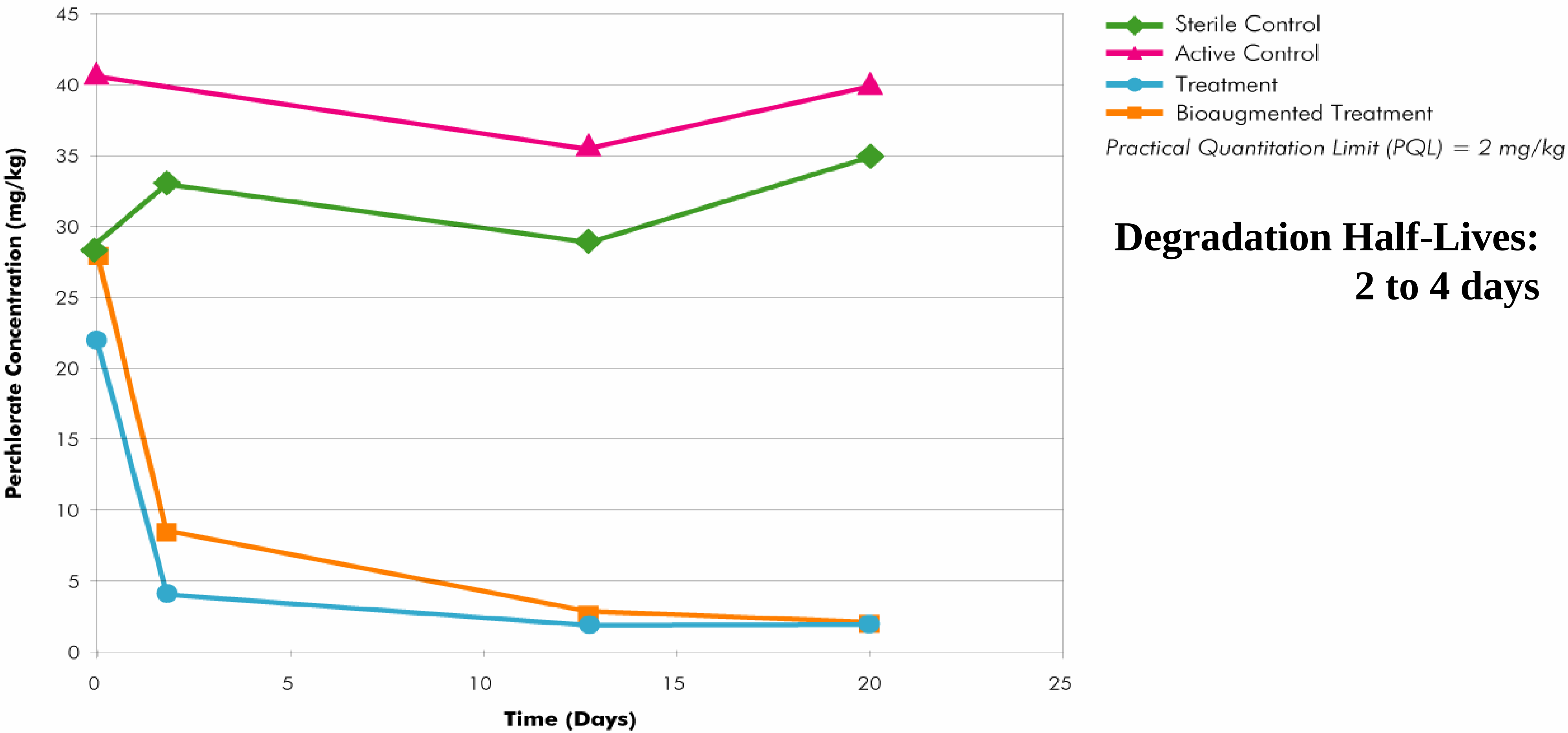
Soil Bioremediation

- Anaerobic bioremediation approach
- Can be used ex situ or in situ
- Successful lab and field demonstrations
  - Perchlorate Burn Area, Aerojet Superfund Site (Site 1)
  - Perchlorate Grinder Station, California (Site 2)
- Technology in commercial use

Site 1. Aerojet Superfund Site

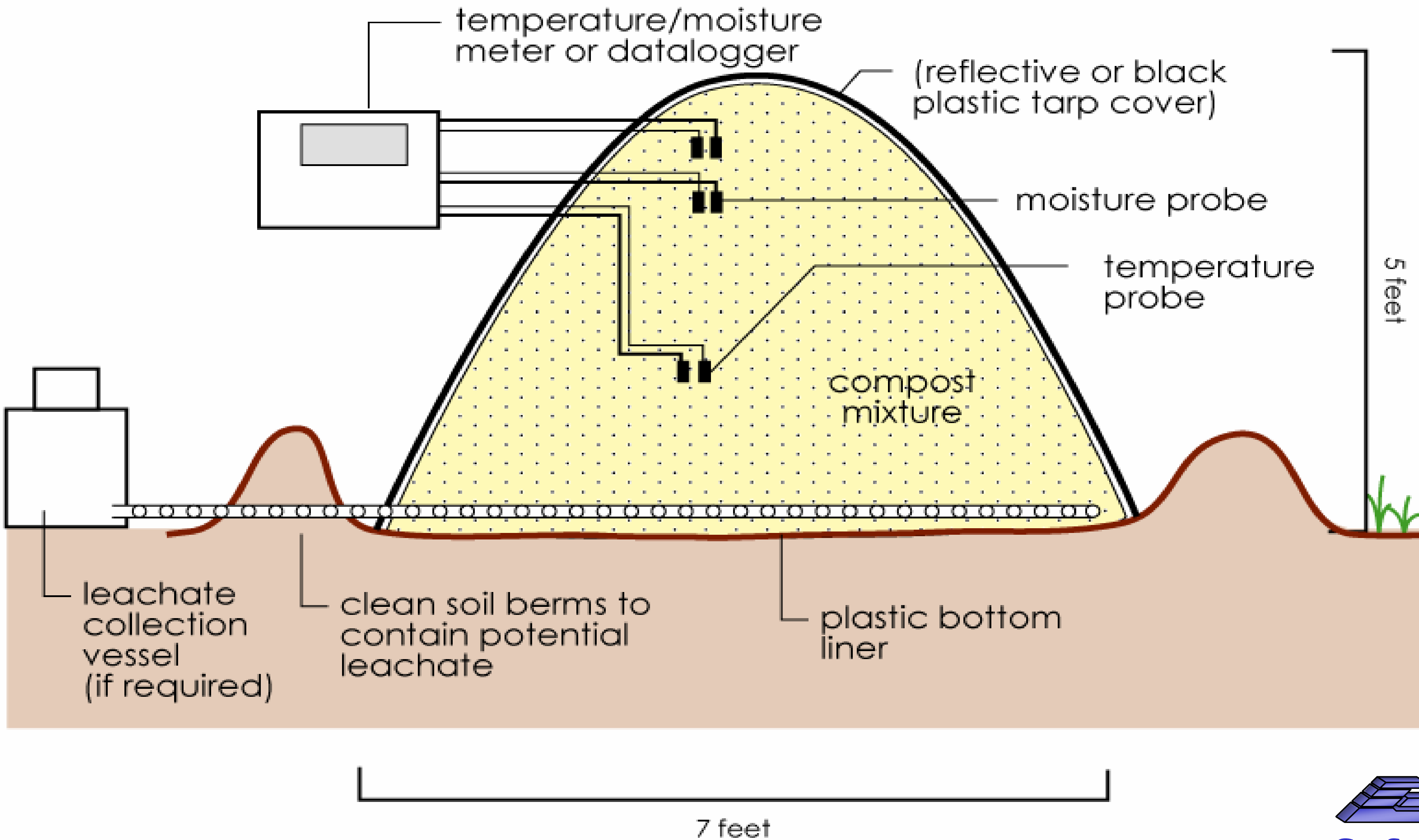
- Former ClO_4 Burn Area
- ClO_4 hot spots up to 4,200 mg/kg
- Silty clay soil, low permeability
- Remedial goal = prevention of perchlorate infiltration to groundwater at concentration >PAL

Site 1: Bench-Scale Results



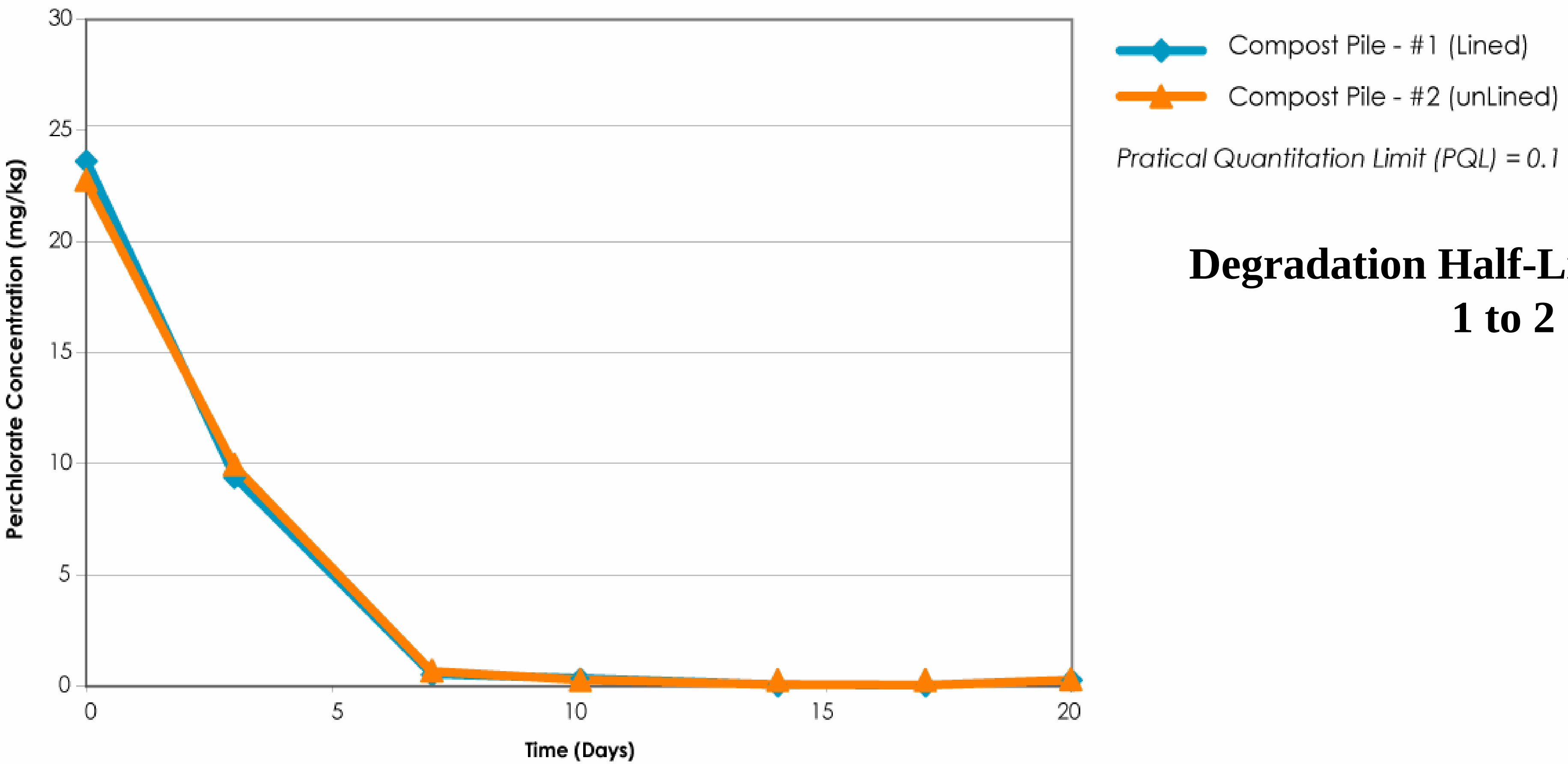
Degradation Half-Lives: 2 to 4 days

Compost Pilot Test Design



GeoSyntec

Site 1: Field Demonstration Results



Pratical Quantitation Limit (PQL) = 0.1 mg/kg

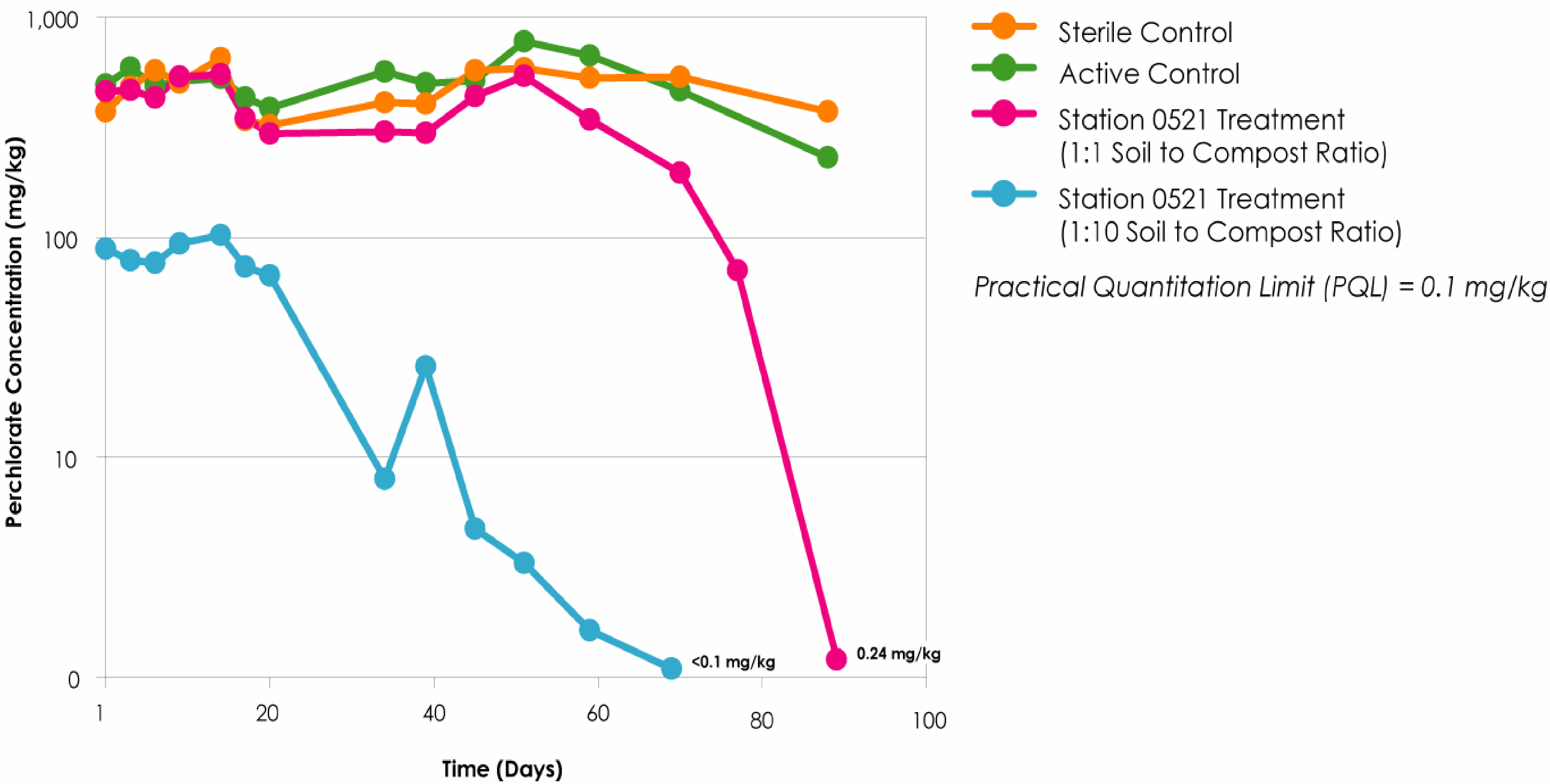
Degradation Half-Lives:
1 to 2 days

Site 2. Rocket Site, California

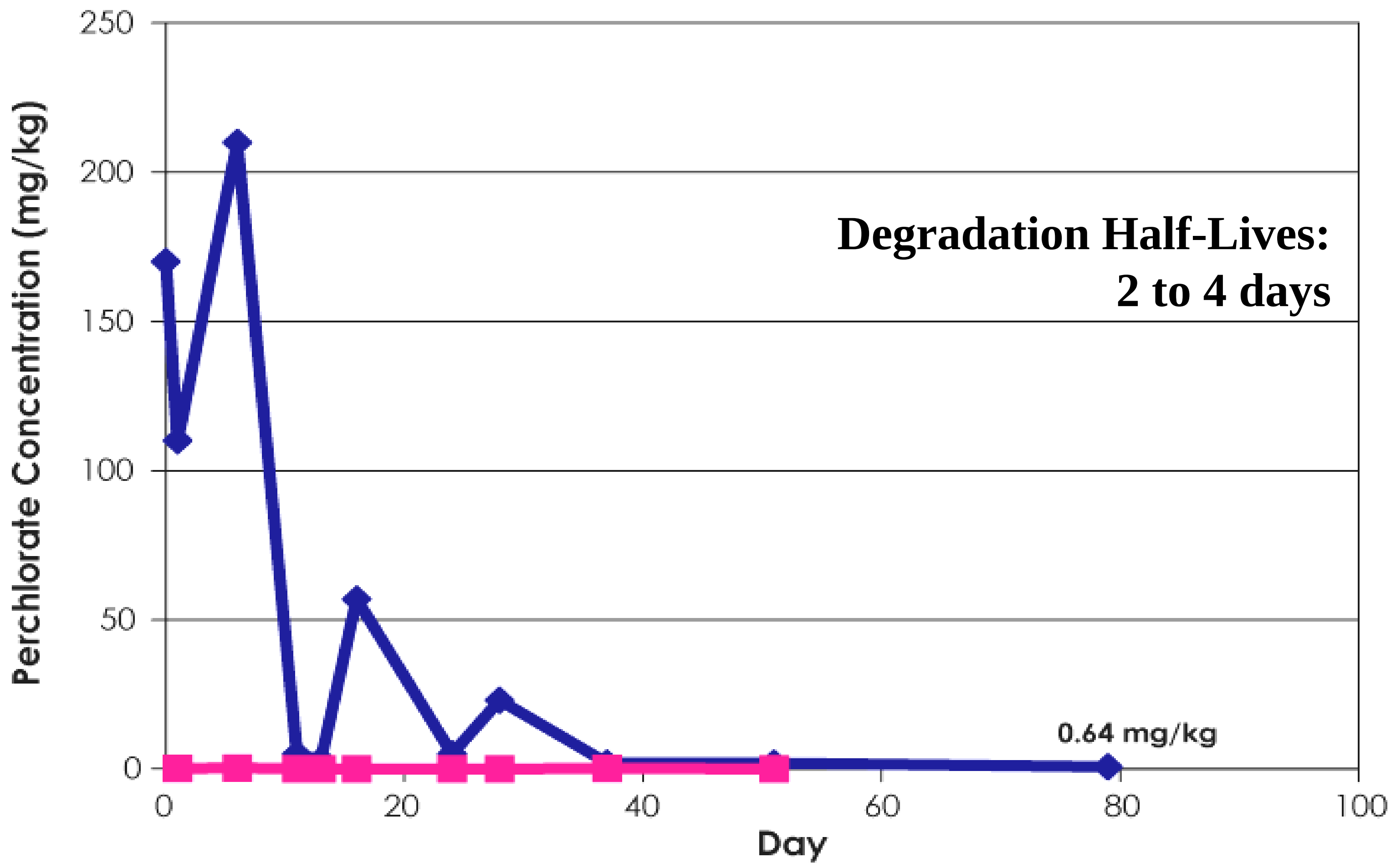
- Active ClO_4 Grinder Station
- ClO_4 hot spots up to 2,100 mg/kg
- Silty soil, low permeability
- Remedial goal = prevention of perchlorate impacts to surfacewater via overland flow during storm events

CSD Bench-Scale Compost Units

Site 2: Bench-Scale Results



Site 2: Field Demonstration Results



Phytoremediation

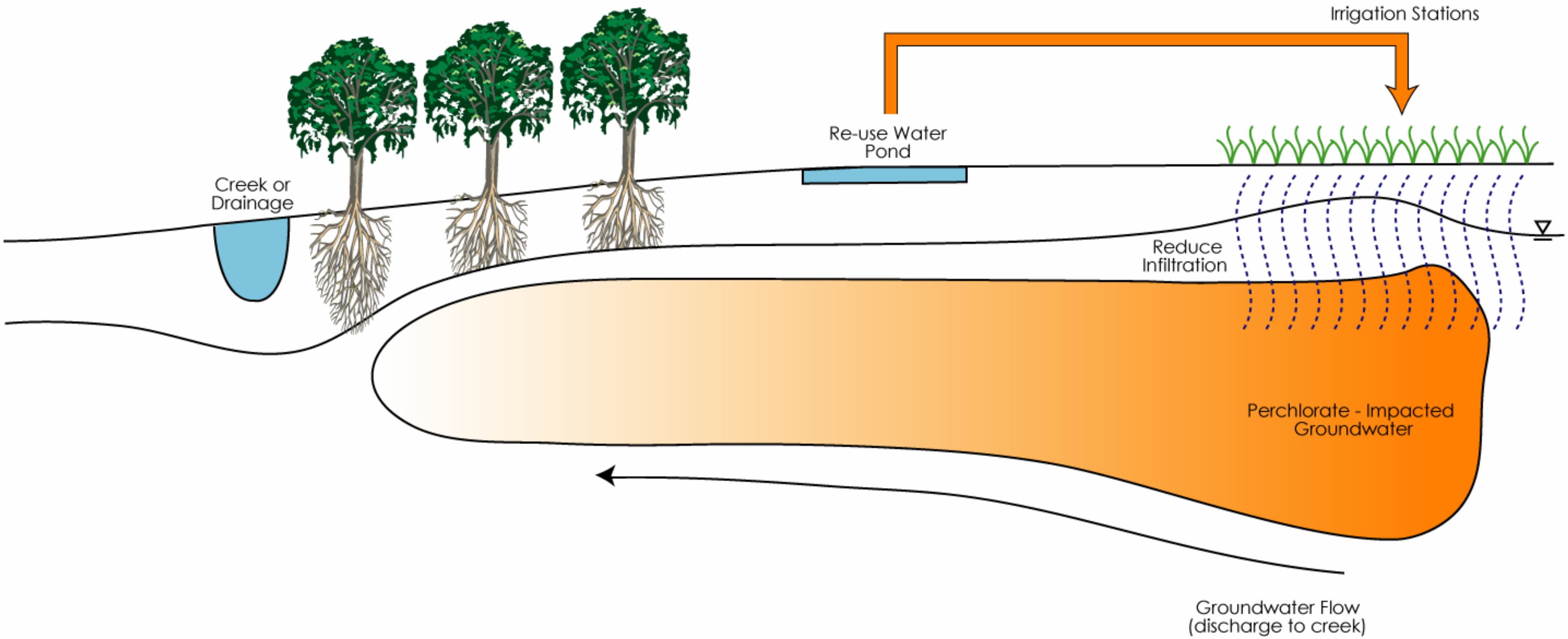
Phytoremediation Goals

- Plants can uptake and accumulate or transform ClO_4
- Phytoremediation being used to:
  - Extract perchlorate from impacted soil
  - Prevent infiltration and/or overland transport
  - Provide hydraulic control of GW, prevent discharge to SW
  - Engineered wetland to treat extracted groundwater

Greenhouse Study Results

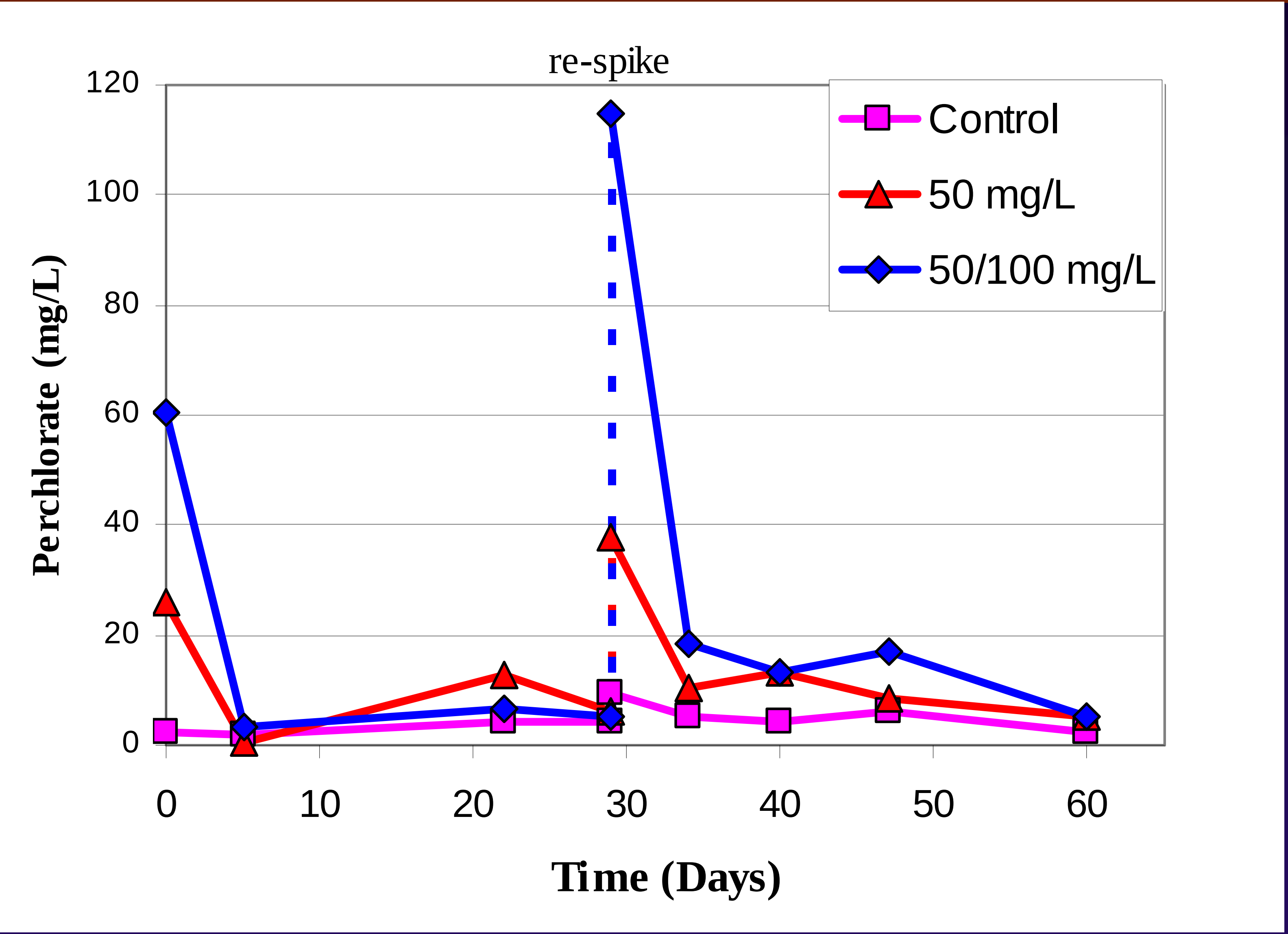
- 4 Plant types (grasses, mustard, alfalfa)
- No germination at 1,000 mg/kg
- Evidence of uptake and transformation (in plant and/or rhizosphere)
- Removals up to 74% from soil; 82% from water
- Alfalfa best plant type tested
- Pilot test of phyto-irrigation using Alfalfa

Conceptualization of Phytoremediation Applications



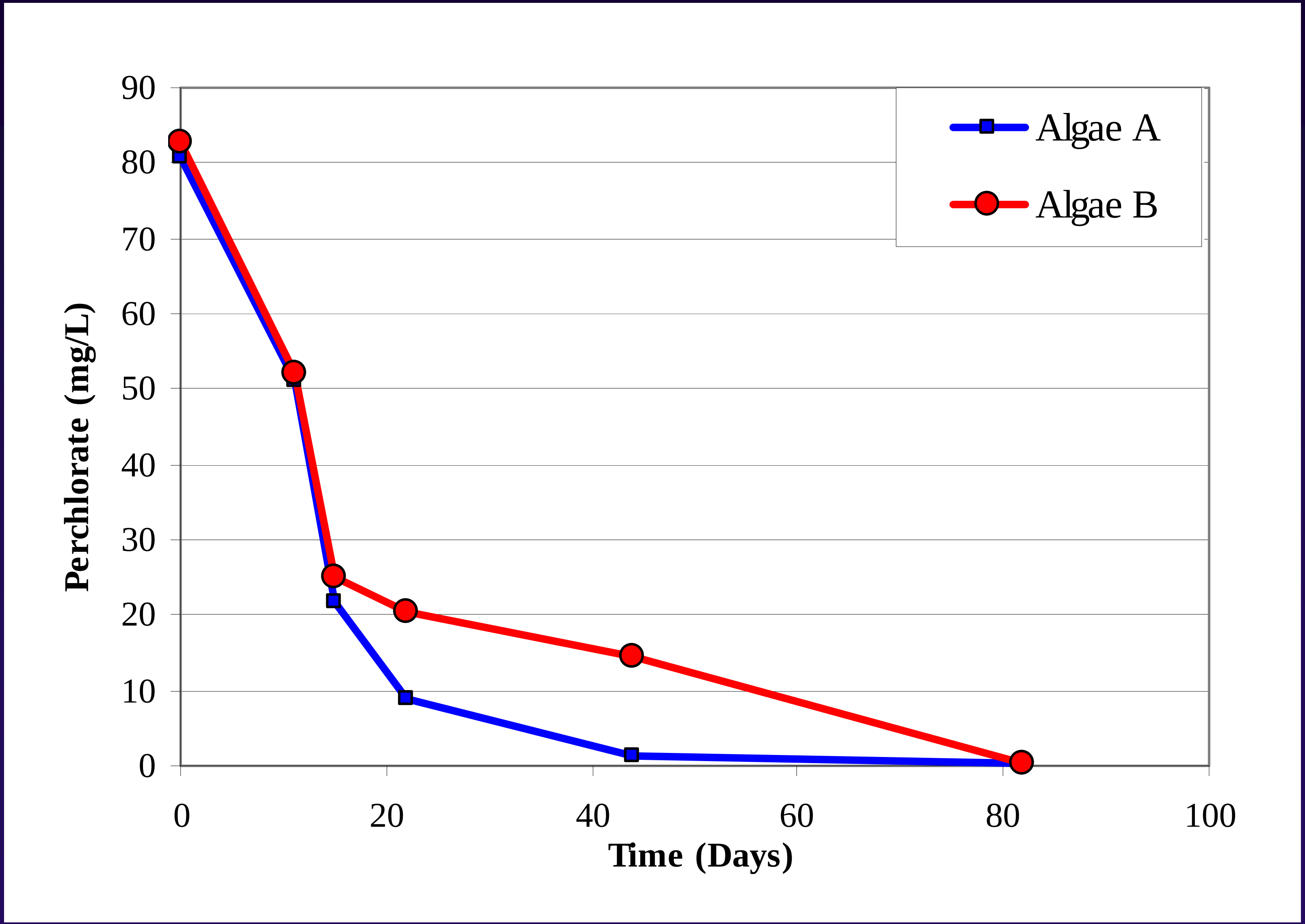
Phytoremediation using Wetland Plants

Perchlorate Mass Loss with Sedges



Phytoremediation using Algae

Perchlorate Mass Loss with Algae



Conclusions

- In situ bioremediation proving to be cost-effective for:
  - Groundwater source destruction
  - Groundwater migration control
- Soil composting proving to be cost-effective to:
  - Reduce ClO_4 impacts to groundwater and surfacewater
- Phytoremediation being used to:
  - Control ClO_4 infiltration, migration and discharge to SW
  - Treat ClO_4 in surfacewater using wetland plants

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